Do Management Practices Impact Cost and Schedule Indicators?
Comparative of Case Studies

José L. Fernández-Solís, Ph.D., Associate Professor, Texas A&M University, Department of Construction Science, 3137 TAMU, College Station, TX 77843 (corresponding author). E-mail: jsolis@arch.tamu.edu
Jing Du, Ph.D., A.M.ASCE, Assistant Professor, Texas A&M University, Department of Construction Science, 3137 TAMU, College Station, TX 77843. E-mail: jdu@arch.tamu.edu
Jorge L. Rincón Fonseca, Graduate Student, Texas A&M University, Department of Construction Science, 3137 TAMU, College Station, TX 77843. E-mail: jrincon99@gmail.com

Abstract

Construction labor productivity has declined over the last 50 years. Contrary to mainstream reporting of significant improvement in construction project productivity through inventions, techniques, methods, and technologies, construction labor productivity has decreased. Is this contradiction real? The research answers the question: is there a significant and measurable difference in project performance (cost, schedule) between projects that use Management by Means (MBR) – using lean construction practices, and Management by Results (MBR) – using traditional construction practices? The research analyzes, compares and draws hypotheses based on cost and schedule differences from planned and actual data, as reported by 70 cases from 7 companies. The aggregate construction cost of these projects is $20.46 billion USD and the aggregate construction size is 35.59M gross square feet. Conclusions bring back two themes of the systemic nature of construction: autonomous agency, and loose coupling. The information-rich data leads us to identify future research using comparative analyses.

Author Keywords

Last Planner System, lean construction practices, management by method, management by result, cost, schedule

INTRODUCTION

Even after initiatives using new techniques and technologies, research indicates that the construction industry has made no significant improvements in labor productivity over the last 50 years (Teicholz 2013). The construction industry, aware of its poor productivity image and high waste, has implemented a number of techniques such as critical path method (CPM), Total Quality Control, Bridging, Project Evaluation and Review Technique (PERT), several Project Delivery Methods, Resource Leveling, Line-of-Balance, Building Information Modeling (BIM) and others (Alarcón 1997; Forbes and Ahmed 2011; Rojas and Aramvareekul 2003, Bølviken and Koskela 2016; Al Nasseri et al. 2016; Hussein and Zaid 2016; Olivieri et al. 2016). The sum of these efforts has not generated a significant impact on the trend on Figure 1, as indicated by Teicholz (2013). Figure 1 suggest that labor productivity for the overall construction industry presents a gradual constant decline over the last five decades, even considering the small peaks. The adjusted line trend indicates a reduction of 0.32% per year, whereas nonfarm industries reflect a 3.06% positive trend per year (Teicholz 2013).

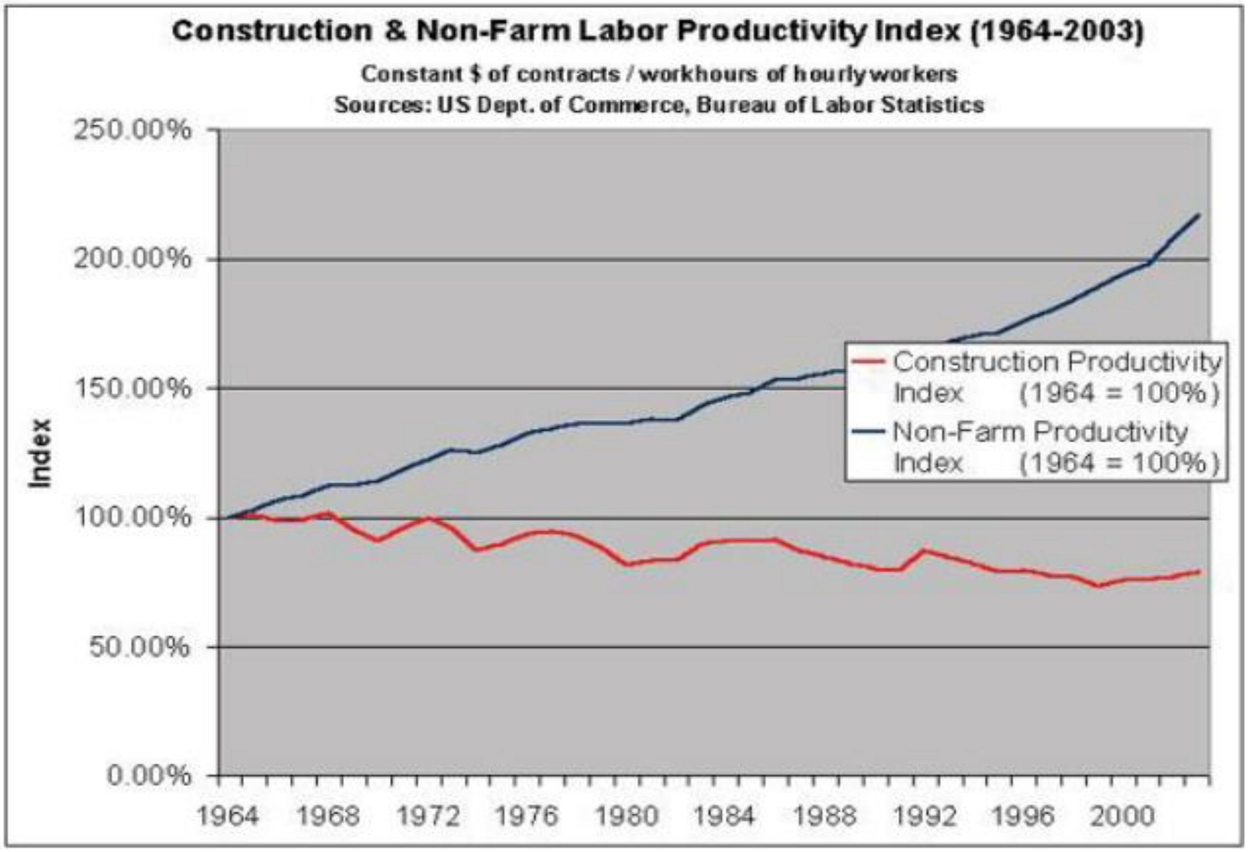


Fig. 1. Labor productivity index for US construction industry and all non-farm industries from 1964 through 2003, national institute of building science (NIBS) 2007

Of particular interest are the claims that a project delivery system, Design Build, and a production management system, Lean Construction, have made regarding productivity increases. Both claim to reduce both construction cost and construction time. However, neither these initiatives nor the implementation of digital drawings that have morphed into Building Information Modeling with increasing dimensions have positively affected construction productivity. According to Sullivan et al. (2017), the improvement claims come from a number of sources:

- DB most effectively controls cost growth (+2.8%), compared to CMR (+5.8%) or DBB (+5.1%)
- No single delivery method consistently performs better on unit cost
- CMR and DB are the most accurate in controlling a project's schedule variation, with an average schedule growth of +10.2 and +10.7%, respectively, as compared with a much higher +18.4% for DBB

The Lean Construction Institute (LCI) has the following website statement:

Dodge Data & Analytics recently benchmarked the current state of capital project delivery performance and found a statistically significant correlation between use of Lean methods and better project outcomes.

- *High Lean intensity projects were three times more likely to complete ahead of schedule and two times more likely to complete under budget*

On schedule and cost performance, which owners cite as most valuable, Dodge found that

- *24% of best projects finished ahead of schedule compared to only 6% of typical projects*
- *46% of best projects finished under budget compared to only 10% of typical projects*
- *A staggering 61% of typical projects finished behind schedule and 49% of typical projects completed over budget*

With close to two decades of novel project delivery systems (PDS), project management systems, information technology applications and others, the claimed improvements in time and cost do not fully answer the question: Why has the labor productivity index, as reported by the National Institute of Building Sciences (NIBS), decreased? To further explore the issue, the Sullivan et al. (2017) and LCI findings noted above will be compared with those of this research in our conclusions.

Production Characteristics – Contrast between Manufacturing and Construction

In manufacturing, a product moves through a production line that is characterized by tightly coupled suppliers that by contract cannot act as autonomous agents. In construction, a parade of specialty contractors' crews' move through the project (creating the product). In other words, in construction, there are no physical or permanent work stations doing repetitive work. In this sense, manufacturing managers do manage production flow (Sacks 2016; Sacks et al. 2017) and are able to permanently identify, study, and minimize waste (Fernández-Solís and Rybkowski 2012).

In modern construction, the general contractor mainly manages risks in the contract with the owner and the multiple, individual, and bounded contracts with the specialty contractors who will do the production work through their crews (foremen or superintendent with a squad of workers). Production consists of parts and labor; this paper focuses on labor. Fernández-Solís' (2008) work on the systemic nature of the construction industry analyzed the peculiarities of construction in contrast to manufacturing (also see Vrijoef and Koskela 2005; Xiao and Fernández-Solís 2016). Two salient peculiarities are the underlying theme of this paper:

- *Loosely coupled systems:* Specialty contractors' workforces constantly change as a project evolves in a creative environment that is very dynamic—this is therefore inefficient and wasteful when compared to manufacturing. Rather than the tight coupling of manufacturing, specialty contractors are loosely coupled in the sense that their contract with the General Contractor requires a level of performance but the General Contractor cannot strictly enforce the performance requirement (Naoum 2016). Hence, specialty contractors often juggle their workforce in response to company strategy and the cumulative needs of all concurrent and forthcoming projects.
- *Autonomous agents*: Today's general contractors manage the business of construction. A project exists because it is a viable business decision and everything within the project comes under the business umbrella. A business responds to the general economy; thus, project stakeholders make decisions that may or may not be the best for the project, but are seen as best for the company at any given point in time. Hence, autonomous agents play powerful roles in the game of the construction business in the general economy.

Production Management Approaches: Traditional and Lean construction

Lean construction and its techniques, such as the Last Planner System, plan percent complete, Takt Time, and others, aim to directly affect and manage the project production across contractual boundaries in a radical new bottom up manner. This research focuses on established categorization of two different management theories, namely Management by Results (MBR) and Management by Means (MBM), and identifies each management style's techniques (see Figure 2).

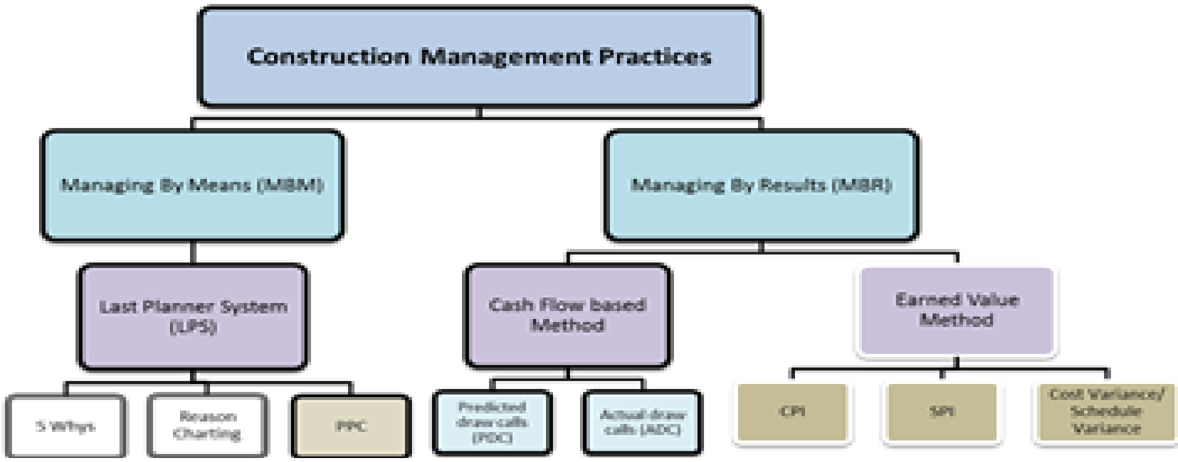


Fig. 2. Comparative chart of management by means and management by results, with example activities used in each method

Management by Results

Management by Results (MBR), as the name suggests, is a target oriented management principle. In MBR, all processes, products and services contribute to the accomplishment of desired goals.

Organizational management focuses primarily on financial outcomes and their relationship with the schedule. Construction managers typically determine the best way to execute a task, its coordination and supervision, and sophisticated general contractors create a cost loaded schedule that informs its cash calls on the monthly applications for payment. This top-down management by results is referred to as a command and control setting and called a "push schedule" (Xiong and Nyberg 2000). Top-down minor changes in the project scope of the work or logistic planning frequently have major schedule and cost implications, and activating corrective adjustments late in a project is often ineffective and expensive (Sterman 1992). In addition, the later the remedial action, the less the ability to influence the project outcomes (Nepal et al. 2006). Along with traditional goals of schedule and budget, factors like client satisfaction and total quality delivery of product and services create success criteria. MBR could be categorized as managing contracts among a parade of singular trades and events, reactively tackling problems as they arise (putting out "fires").

Management by Means

Management by Means (MBM), on the other hand, is a new Lean Construction philosophy (Johnson 2006; Kim 2017), which focuses on resources, rather than finances, to achieve long term success through improvement in process, methods, approaches and their interrelations (Johnson and Brooms 2000; Kim 2017). In lean, the planning and emphasis exist at the tactical level where the project is executed. Those that do the work plan and monitor the work progress, which is overseen by the management team. The management team focuses on the macro level of milestone scheduling and target values while the executing team focuses on meeting milestones and budgeted costs.

Contrast of MBR and MBM

In the MBM model, the organization (strategic, economics, contractual) and logistics (managerial, planning, specialty contractors) levels support the foremen (Gambatese et al. 2016) and work crews (tactical, production). MBM and lean construction practices are geared to anticipate, identify, avoid and prevent obstacles and problems in the production of construction and across specialty contractors' contract boundaries. Lean construction has been called a new paradigm and has been attributed with creating, through methods, techniques and education, a new management culture in construction. The center of action is transferred from the office to the site. The last planner is a site location base for managing a building's production.

Conversely, in MBR (see Figure 3), the organization (strategic) and the logistics (managerial) levels focus on the economics in a contractual way, with the tactical or execution levels being subservient. MBR is the classic management approach to planning in which a plan is expected to be executed with results equal to the plan (classic communication theory, the thermostat model) (Koskela and Howell 2002a, 2002b). Figure 3 illustrates the organizational culture change that lean construction has brought to the industry through successful implementation of Last Planner System techniques (Fernández-Solís 2008).

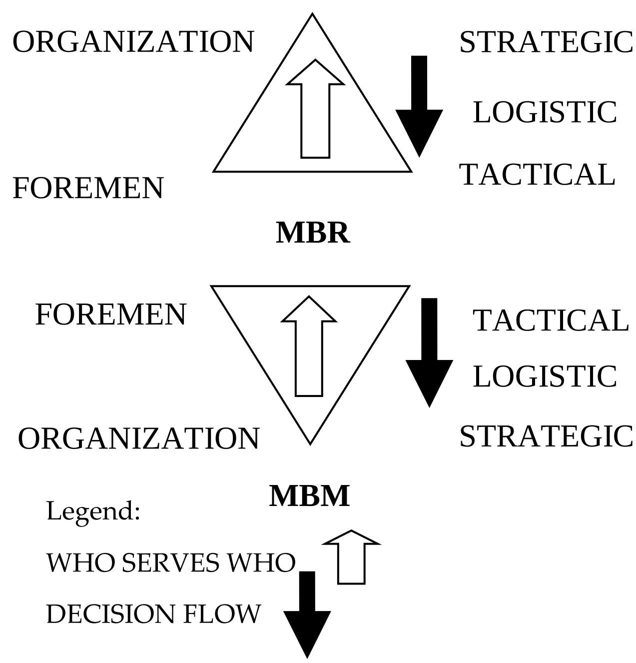


Fig. 3. Top down and bottom up management styles

Hypothesis

The LPS, as depicted, creates an upside-down organizational culture. The question remains: does this paradigm change in culture produce different results under different project delivery and contract systems?

Drawing on knowledge of both methods, the hypothesis of this paper is as follows: there is a significant and measurable difference in project performance (cost, schedule and PPC) between projects that use the MBR and MBM approaches. In other words, it is project and expect to find that projects with MBM have a better cost and time performance under different project delivery and contract systems. If this hypothesis is not proven, then a subsequent conjecture on the probable causes.

Case Study Method

The case studies selected come from projects with the following data:

- Project final completion date
- Total construction in place cost
- Total amount of building square feet

- Types of construction contracts (construction sealed proposal and guaranteed maximum price)
- Two types of project delivery systems (construction management at risk and design build)
- If a lean project, the Planned Percent Complete data was available
- Planned versus actual cost and schedule by systems was available

The above data was translated into a common template as explained below. Only commercial type general construction projects were considered.

Research Method

The research design goes through several phases: problem statement; design of data collection template; design of case studies for data collection; expected types of statistical analysis; data collection; analysis of data using statistical methods; findings and interpretation; conclusions and observations; and future work.

Problem Statement

The research method addresses the question of whether the last planner system impacts project performance through its construction management practices. The research starts with a structured literature review (SLR) which focuses on the two management theories of interest, specifically Management by Means (MBM) and Management by Results (MBR).

A uniform data collection template was created based on best practices and the SLR. Seventy (70) cases were identified over a period of six years that were under two project delivery systems (Design Build [DB] and Construction Management at Risk [CMAR]) and two types of contract types (Contract Sealed Proposal [CSP] and Guaranteed Maximum Price [GMP]). The collected data in the template uses ten divisions for cost and time on the project. Each division has two sets of collected data: planned and actual. In addition, the Plan Percent Complete was calculated for the duration of the work in each division. A comparative statistical analysis was completed between project management types, project types, project delivery systems, and contract types.

Design of Data Collection Template

Formoso and Moura (2009) produced one of the first quantitative research papers evaluating the impact of the last planner system on the cost and time aspects of construction projects. In this research, the same indicators as Formoso and Moura were used: the cost deviation indicator (ratio between incurred and budget cost), time deviation (ratio between real and expected duration), and the earned value method (S curve) (Kim and Ballard 2010). Since then, other researchers, such as Viana et al. (2010), Porwal et al. (2010), McConaughy and Shirkey (2013), Khanh and Kim (2016), Priven and Sacks (2016) and Hamzeh et al. (2016) have followed with metrics and statistical analysis. These papers compare, contrast, and analyze projects using lean metrics of plan percent complete in cost and time variations.

Building on Formoso and Moura's work, it was created a template to acquire uniform and comparable data across companies and projects. While their paper and others have compared discreet project cost and time planned versus actual data along with the project reported PPC, a matrix of ten project building systems was used (see Table 1). Metrics in this table are ratios, as in Formoso and Moura's paper.

Table 1 items are outlined in the legend below:

Table 1. Template for collecting cost, time and ppc data using categories of building systems

Project:	Year:	Economy*:		CIP:			MBM
Contract:	PDS:			Type:			/ MBR
GSF:		Cost $/GSF			Time - months		PPC
Bldg. Syst.	**Plan**	**Actual**	**Delta**	**Plan**	**Actual**	**Delta**	**(MRM only)**
Sitework							
Foundations							
Structural							
Exterior wall							
Interior finishes							
Vertical transp.							
Mechanical							
Electrical							
GC direct							
Totals							

- *MRM (management by means):* Lean Construction management approach that focuses on resources, rather than finances, to achieve long term success through improvement in process, methods, approaches and their interrelations
- *MBR (management by results):* target oriented management principle where all processes, products and services contribute to the accomplishment of desired goals.
- *Project:* each project identified by a number
- *Year:* issue of certificate of occupancy and economic cycle (Expansion, Boom, Recession, Depression)
- *CIP:* $ in millions of construction in place – cost
- *Contract:* Contract Sealed Proposal (CSP best value) or Guaranteed Maximum Price (GMP)
- *PDS:* project delivery system – Design Build (DB) or Construction Management at Risk (CMAR)
- *Type:* Commercial (COM)
- *GSF:* Gross Square Feet
- *Cost:* aggregate building system in US dollars per gross square feet (GSF); costs escalated to reflect net present day value (January 2017)
- *Time:* building system activity in months
- *Building systems:* aggregate of trades and their contribution to the particular stated building system
- *Plan:* building system cost or activity time as planned
- *Actual:* final cost and time to completion of the system activity
- *Delta:* difference between planned and actual
- *PPC:* aggregate plan percent complete of all trades in a building system for the duration of the building system construction

Design of Case Studies

Three companies provided the data. One company already was segregating its data by the above building system schema. The other two companies provided the data by specialty contractors' crews and with the help of the first company, researchers were able to reassemble the data to fit the same format with a high level of confidence that we were not introducing significant errors. The types of projects, contracts, and project delivery systems used varied for both MBM and MBR (see Table 2).

Table 2. Number and percentage of mbm / mbr cases segregated per contract and project delivery system

Project Mgmt. types / No. of cases	PDS types / No. of cases	Contract types / No. of cases	
		CSP	**GMP**
MBM / 20 27.4%	DB / 6 8.2%	1 / 1.4%	6 / 6.8%
	CMAR / 14 19.2%	9 / 12.3%	5 / 6.8%
MBR / 53 72.6%	DB / 10 13.7%	3 / 4.1%	7 / 9.6%
	CMAR / 43 58.9%	26 / 35.6%	17 / 23.3%
Totals / %		**39 / 53.4%**	**34 / 46.6%**

Although other PDSs (Puddicombe and Johnson 2012), such as Design-Bid-Build (DBB) and Construction Management Agent (CMAG), were available, we decided to limit the study to the more prevalent types--Design Build (DB) and Construction Management at Risk (CMAR). For project types, we considered public (e.g., academic buildings, classrooms and offices) and private buildings in the same commercial category.

The ratio of DB vs. CMAR cases approximates that of the industry as reported by their respective organizations (Design Build Institute of America and Construction Management At Risk). This was not a consideration in the solicitation of cases from the GC, and can be attributed to coincidence. The ratio of CSP and GMP is almost equal. This is also the current estimate in the industry for contracts at large with the understanding that there are several other types of contracts also employed, but in lower numbers.

Table 3. Cases per project delivery system

PDS	NO.	%
CMAR	57	78.1%
DB	16	21.9%

Design Build projects include design costs, and Construction Management at Risk includes pre-construction costs as an integral part of the construction in place cost (CIP). Therefore, the design and preconstruction costs are not segregated in the data. If Design Bid Build were used, the CIP would not have included design cost aspects and therefore, we determined that different risks needed to be included.

Plan Percent Complete

Lean construction's plan percent complete (PPC) gauges the reliability of promises made, is a useful and viable indicator of the quality of the schedule, and serves as a surrogate measure of project flow–-how smoothly or chaotically a project runs. Project schedule directly affects cost; therefore, a cost loaded schedule relates one to the other when contrasted with the project's original schedule of values that projected, for the owner, when to expect the cash calls. The PPC is operationalized as an index that meta-project stakeholders can use to calibrate the reliability of work in progress and provide feedback on the predictability/variability of logistical plans. A PPC is a broad, mutual fund-like indicator of project flow quality and of the reliability of the logistics schedule, tracking promises made at the tactical level (Fernández-Solís et al. 2015).

A PPC follows the formula in Figure 4:

$$\text{PPC\%} = \frac{\text{Number of completed tasks}}{\text{Number of planned tasks}} \times 100$$

Fig. 4. Planned percent complete formula

However, further qualifications must be made when using a PPC mutual fund as an index to analyze and evaluate a project performance in time. Fernández-Solís et al. (2015) have shown that aggregating specialty contractors' PPCs in order to access one project PPC can be misleading. One sub may be low and another high, thereby masking the actual entropy or chaos that may be occurring. It is best to have PPC readings at the foremen crew level but if not possible, at the specialty contractor and crew level (Fernández-Solís et al. 2013). In our case, we have segregated the PPC according to the ten building systems divisions. By having one system across multiple projects, multiple project types, multiple contract types and multiple project delivery types, we hope to normalize what otherwise could be disparate readings.

Expected Type of Statistical Analysis

In the literature review, most managers implement MBR by assigning and tracking costs on weekly tasks. MBM uses a bottom up process called the Last Planner System (Kim and Ballard 2010) in conjunction with traditional cost and schedule tracking. Both MBM and MBR projects create a schedule of values used in their monthly application for payment and a cost loaded schedule that tracks planned versus actual cost progress over time.

The primary comparative analysis is between the xxx MBM and the yyy MBR case studies. Focus is also on the comparative relationship of MBM and MBR regarding several variables: building type (commercial and residential); contract type (CSP and GMP), and project delivery system (DB and CMAR).

We also compare the projects along a timeline to observe any improvements from earlier projects. Lastly, we compare the building systems' performance across time and to each other. The analysis employs regression analysis techniques using several steps: (1) Descriptive analysis of the variables; (2) Pearson correlation (to assess relationships between two variables), (Downing and Clark 2005); (3) Multivariate regression techniques (to discover relationships between a dependent variable and one or more independent variables), (Hair et al. 1998); (4) Assess the precision of the regression equation by the method of least squares (the coefficient of determination, R^2, represents the percentage of the dependent variable explained by the independent ones), (Hair et al. 1998); and (5) ANOVA is a collection of statistical models used to analyze the differences among group means and their associated procedures. It provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the T-tests to more than two groups, (Fisher 1918).

Analysis of Data Using Statistical Methods

The purpose of this statistical analysis is to understand the driving factors of project time and cost performance. In this study, we consider the following control variables:

- X1: Management theory (MBM or MBR)
- X2: Contract type (GMP or CSP)
- X3: Project delivery method (DB or CMAR)

The project performance indicators to be tested include:

- Y1: Cost overrun ratio (actual cost over budget)
- Y2: Time overrun ratio (actual duration over planned duration)

To provide direct empirical evidence, we collected and analyzed data from 70 projects, dating from 2000 to 2017. The data includes commercial projects. The total contract value of these 70 projects is \$20.46 billion, and the total area size is 35.59 million square feet. The distributions of all three control variables are illustrated in Figure 5.

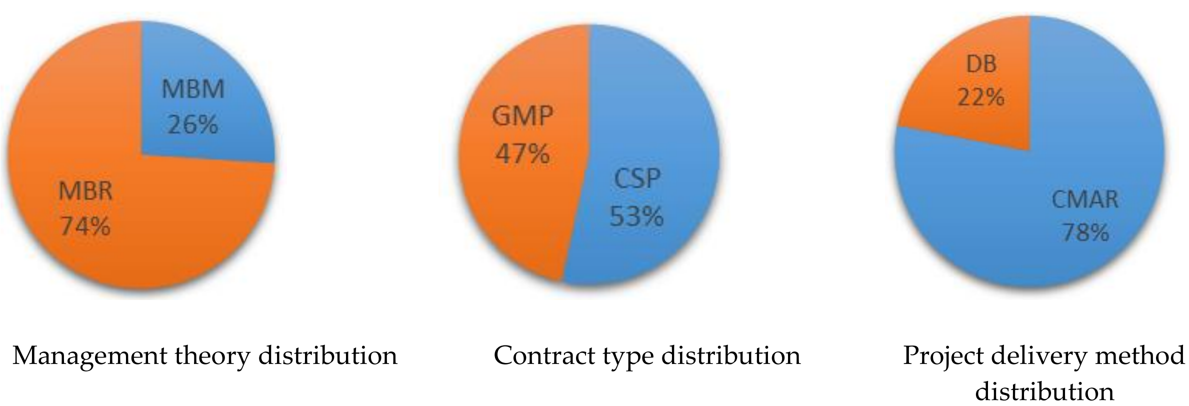
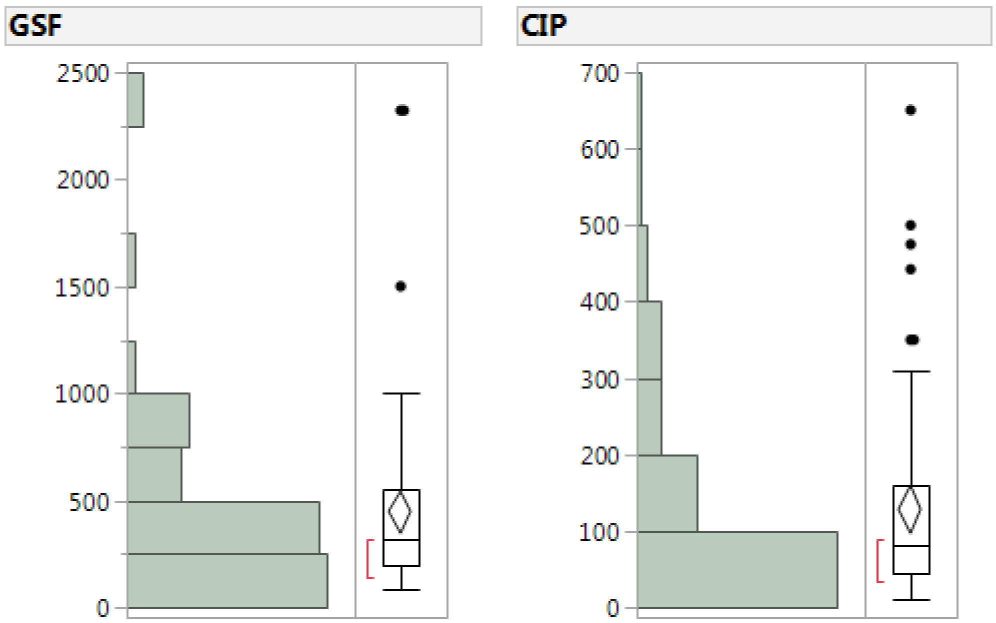


Fig. 5. Distribution of control variables

Figure 6 captures the distribution of GSF and Construction Cost in Place of the 70 projects. The projects reported are considered by the industry to be large. There are no billion dollar projects reported in this set but neither there are smaller projects (less than \$5M USD). This may affect the results as indicated in the conclusions.



GSF

Quantiles

100.0%	maximum	2320
99.5%		2320
97.5%		2320
90.0%		858.1
75.0%	quartile	550.75
50.0%	median	320
25.0%	quartile	198.375
10.0%		150.3
2.5%		96.625
0.5%		85
0.0%	minimum	85

Summary Statistics

Mean	445.93043
Std Dev	419.08894
Std Err Mean	50.090709
Upper 95% Mean	545.85866
Lower 95% Mean	346.0022
N	70

CIP

Quantiles

100.0%	maximum	650
99.5%		650
97.5%		533.75
90.0%		309
75.0%	quartile	160
50.0%	median	80.435
25.0%	quartile	45.375
10.0%		35.56
2.5%		18.155
0.5%		11.8
0.0%	minimum	11.8

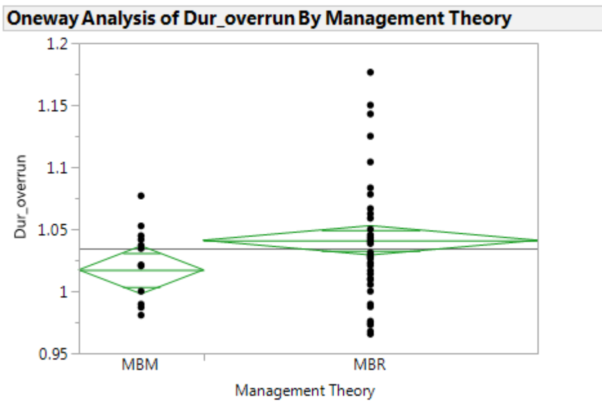
Summary Statistics

Mean	128.60586
Std Dev	128.35809
Std Err Mean	15.341726
Upper 95% Mean	159.21176
Lower 95% Mean	97.999951
N	70

Fig. 6. Statistics of the 70 cases: GSF and construction in place (CIP)

Impacts of Management Theory (X1)

First, we explored the impacts of management theory on project time and cost performance. ANOVA analyses were performed to examine if there is a significant difference between the two management theories. Figure 7illustrates the ANOVA analysis results:



Excluded Rows 3

Oneway Anova

Summary of Fit

Rsquare	0.060689
Adj Rsquare	0.046876
Root Mean Square Error	0.042275
Mean of Response	1.034628
Observations (or Sum Wgts)	70

Analysis of Variance

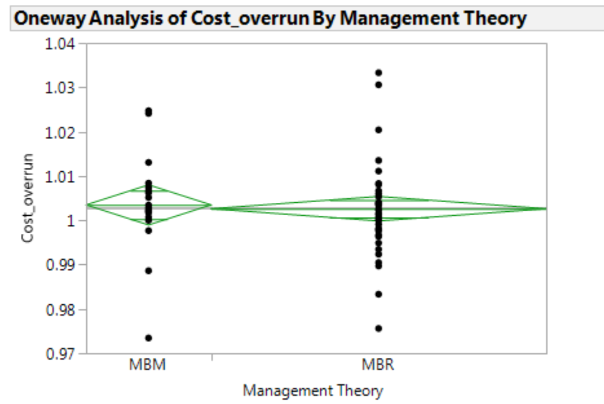
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Management Theory	1	0.00785212	0.007852	4.3935	0.0398*
Error	68	0.12153068	0.001787		
C. Total	69	0.12938280			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM	19	1.01728	0.00970	0.9979	1.0366
MBR	51	1.04109	0.00592	1.0293	1.0529

Std Error uses a pooled estimate of error variance

a: impacts of management theory on time performance



Excluded Rows 3

Oneway Anova

Summary of Fit

Rsquare	0.00154
Adj Rsquare	-0.01314
Root Mean Square Error	0.009893
Mean of Response	1.002861
Observations (or Sum Wgts)	70

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Management Theory	1	0.00001026	0.000010	0.1049	0.7471
Error	68	0.00665575	0.000098		
C. Total	69	0.00666601			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM	19	1.00349	0.00227	0.99896	1.0080
MBR	51	1.00263	0.00139	0.99986	1.0054

Std Error uses a pooled estimate of error variance

b: impacts of management theory on cost performance

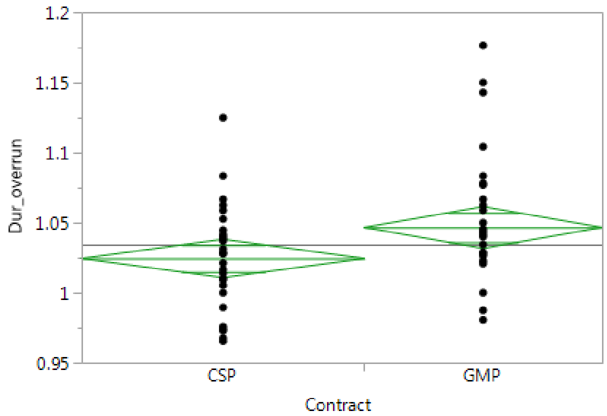
Fig. 7. Impacts of management theory on project time and cost performance

The results find that management method significantly affects project time performance ($p=0.0398<0.05$). On average, MBM-driven projects overrun time by 1.7%, while MBR-driven projects overrun time by 4.1%, indicating that MBM improves project time performance. However, we did not observe a significant difference between MBM-driven and MBR-driven projects in terms of cost performance ($p=0.7471>0.05$). This may be due to the lack of data about project profits and project change orders, both of which play an important role in a project's final cost.

Impacts of Contract Type (X2)

Then we examined the impacts of different contract types on project time and cost performance. Fig 8 illustrates the results of the ANOVA analyses:

Oneway Analysis of Dur_overrun By Contract



Excluded Rows 3

Oneway Anova

Summary of Fit

Rsquare	0.065711
Adj Rsquare	0.051971
Root Mean Square Error	0.042162
Mean of Response	1.034628
Observations (or Sum Wgts)	70

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Contract	1	0.00850188	0.008502	4.7826	0.0322*
Error	68	0.12088092	0.001778		
C. Total	69	0.12938280			

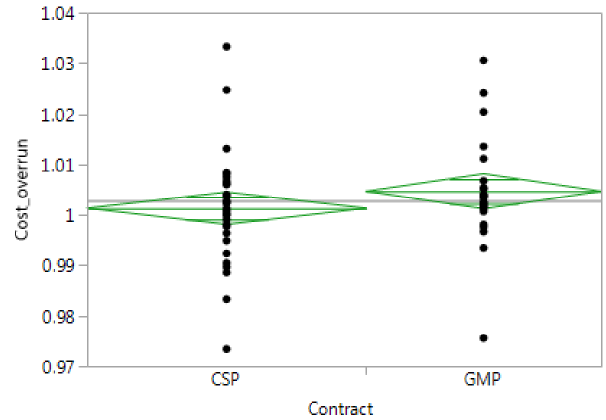
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CSP	38	1.02451	0.00684	1.0109	1.0382
GMP	32	1.04664	0.00745	1.0318	1.0615

Std Error uses a pooled estimate of error variance

a: impacts of contract type on time performance

Oneway Analysis of Cost_overrun By Contract



Excluded Rows 3

Oneway Anova

Summary of Fit

Rsquare	0.028961
Adj Rsquare	0.014681
Root Mean Square Error	0.009757
Mean of Response	1.002861
Observations (or Sum Wgts)	70

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Contract	1	0.00019305	0.000193	2.0281	0.1590
Error	68	0.00647296	0.000095		
C. Total	69	0.00666601			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CSP	38	1.00134	0.00158	0.9982	1.0045
GMP	32	1.00467	0.00172	1.0012	1.0081

Std Error uses a pooled estimate of error variance

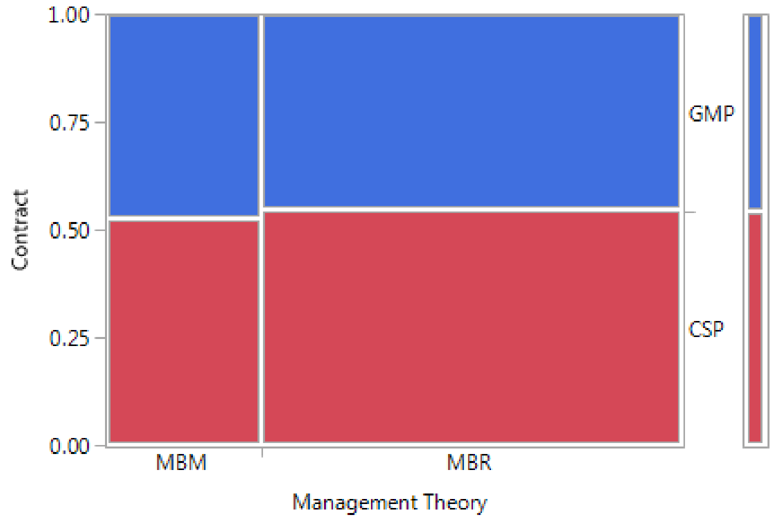
b: impacts of contract type on cost performance

Fig. 8. Impacts of contract type on project time and cost performance

The results find that contract type also has a significant effect on project time performance (p=0.0322<0.05). On average, projects using CSP overrun time by 2.5%, while projects using GMP overrun time by 4.7%. There is no significant difference between CSP and GMP projects on cost performance (p=0.159>0.05). This result may be attributed to the potential multicollinearity issue, i.e., the impacts of contract type may be caused by management method, if a certain method is always tied to a certain type of contract. As a result, a contingency analysis examine if there is a relationship between management method and contract type. Our analysis eliminates this possibility (Figure 9).

Contingency Analysis of Contract By Management Theory

Mosaic Plot



Contingency Table

Contract

Management Theory	Count / Total % / Col % / Row %	CSP	GMP	Total
MBM	Count	10	9	19
	Total %	14.29	12.86	27.14
	Col %	26.32	28.13	
	Row %	52.63	47.37	
MBR	Count	28	23	51
	Total %	40.00	32.86	72.86
	Col %	73.68	71.88	
	Row %	54.90	45.10	
Total	Count	38	32	70
	Total %	54.29	45.71	

Tests

N	DF	-LogLike	RSquare (U)
70	1	0.01436149	0.0003

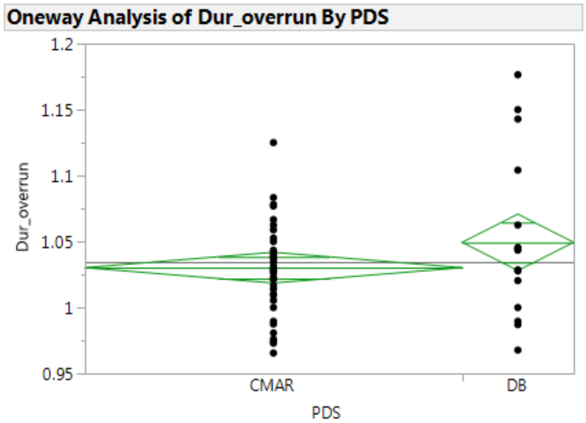
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	0.029	0.8654
Pearson	0.029	0.8654

Fisher's Exact Test	Prob	Alternative Hypothesis
Left	0.5384	Prob(Contract=GMP) is greater for Management Theory=MBM than MBR
Right	0.6705	Prob(Contract=GMP) is greater for Management Theory=MBR than MBM
2-Tail	1.0000	Prob(Contract=GMP) is different across Management Theory

Fig. 9. Contingency test between management theory and contract type

Impacts of Project Delivery Method (X3)

We also examined the impacts of different project delivery methods on project time and cost performance. Figure 10 illustrates the results of the ANOVA analyses:



Excluded Rows 3

Oneway Anova

Summary of Fit

Rsquare	0.035101
Adj Rsquare	0.020911
Root Mean Square Error	0.042847
Mean of Response	1.034628
Observations (or Sum Wgts)	70

Analysis of Variance

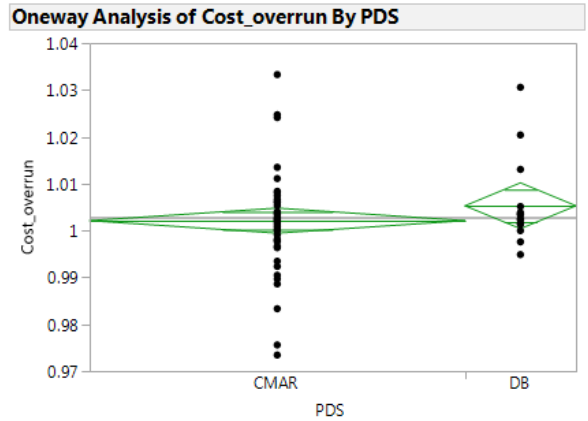
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PDS	1	0.00454141	0.004541	2.4737	0.1204
Error	68	0.12484139	0.001836		
C. Total	69	0.12938280			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CMAR	54	1.03024	0.00583	1.0186	1.0419
DB	16	1.04942	0.01071	1.0280	1.0708

Std Error uses a pooled estimate of error variance

a: impacts of project delivery method on time performance



Excluded Rows 3

Oneway Anova

Summary of Fit

Rsquare	0.018551
Adj Rsquare	0.004118
Root Mean Square Error	0.009809
Mean of Response	1.002861
Observations (or Sum Wgts)	70

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
PDS	1	0.00012366	0.000124	1.2853	0.2609
Error	68	0.00654235	0.000096		
C. Total	69	0.00666601			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CMAR	54	1.00214	0.00133	0.9995	1.0048
DB	16	1.00530	0.00245	1.0004	1.0102

Std Error uses a pooled estimate of error variance

b: impacts of project delivery method on cost performance

Fig. 10. Impacts of project delivery method on project time and cost perfomance

The results find that project delivery method affects neither project time performance (p=0.1204>0.05) nor cost performance (p=0.2609>0.05).

Findings and Interpretation

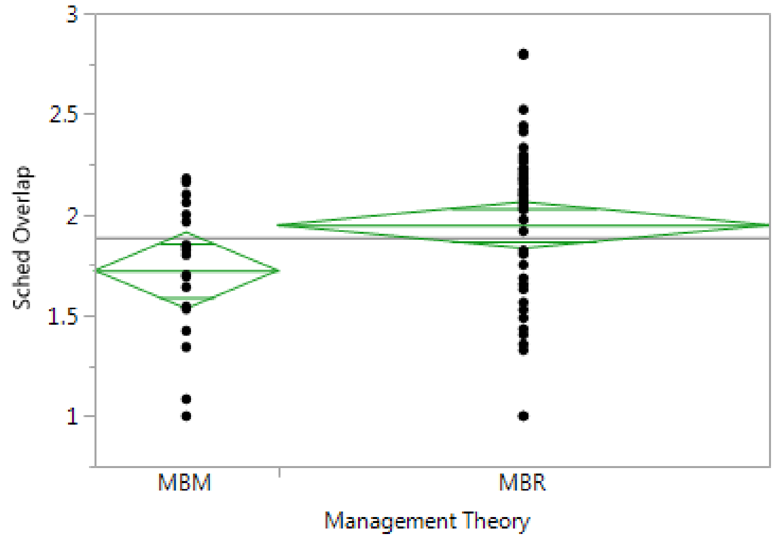
An Exploratory Analysis of Scheduling Practice under Different Management Methods

Our preliminary analysis finds that MBM helps improve project time performance. Because we are interested in understanding the underpinning process that leads to better time performance under MBM, we developed a scheduling practice metric called Schedule Overlap:

$$s.o. = \sum_{i=1}^{n} d_i / d$$

Where *s.o.* is the schedule overlap ratio, d_i is the planned duration of the i^{th} craft, n is the number of crafts, and d is the planned project duration. In other words, *s.o.* reflects the level of effort a project team expends on different crafts in parallel. Figure 11 illustrates that under MBR, projects tend to have a larger s.o. ($p=0.046<0.05$).

Oneway Analysis of Sched Overlap By Management Theory



Excluded Rows 3

Oneway Anova

Summary of Fit

Rsquare	0.057255
Adj Rsquare	0.043391
Root Mean Square Error	0.412664
Mean of Response	1.887257
Observations (or Sum Wgts)	70

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Management Theory	1	0.703266	0.703266	4.1298	0.0460*
Error	68	11.579835	0.170292		
C. Total	69	12.283100			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
MBM	19	1.72304	0.09467	1.5341	1.9120
MBR	51	1.94844	0.05778	1.8331	2.0637

Std Error uses a pooled estimate of error variance

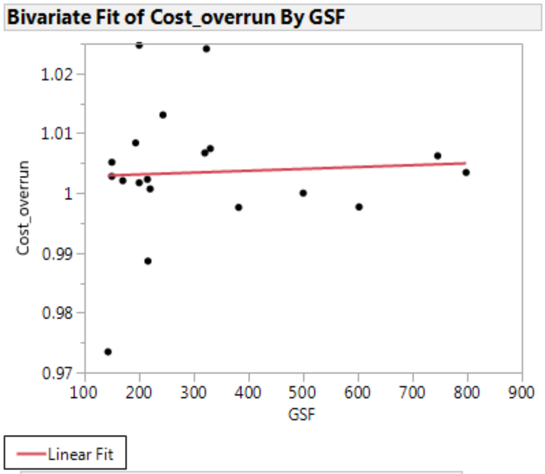
Fig. 11. Schedule overlap under different management theories

This result sounds counterintuitive because the literature suggests that concurrent execution of project works would improve project time performance, while our discovery is that less overlapped execution leads to better project time performance. Our hypothesis is that under MBM, the project activities within the same craft are optimized in terms of a streamlined workflow, and thus, there is less need to overlap craft level efforts. This hypothesis deserves further investigation in future research.

Impacts of GSF and CIP – MBM only

This analysis tests if GSF or CIP (MBM projects only) affect project cost or time performance.

Figure 12 is a regression analysis of GSF's impacts on cost and time performance. Results indicate that the area size of projects do not affect project cost and time performance.



Linear Fit

Cost_overrun = 1.0024882 + 3.1134e-6*GSF

Summary of Fit

RSquare	0.003106
RSquare Adj	-0.05553
Root Mean Square Error	0.011479
Mean of Response	1.003488
Observations (or Sum Wgts)	19

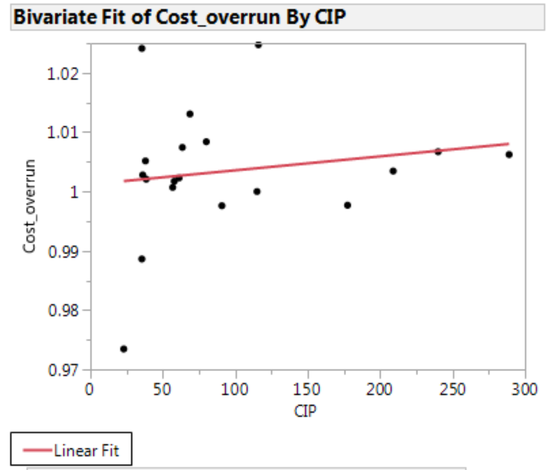
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00000698	6.98e-6	0.0530
Error	17	0.00224016	0.000132	Prob > F
C. Total	18	0.00224714		0.8207

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.0024882	0.005081	197.32	<.0001*
GSF	3.1134e-6	1.353e-5	0.23	0.8207

Regression analysis between GSF and cost overrun



Linear Fit

Cost_overrun = 1.001221 + 2.3513e-5*CIP

Summary of Fit

RSquare	0.02641
RSquare Adj	-0.03086
Root Mean Square Error	0.011344
Mean of Response	1.003488
Observations (or Sum Wgts)	19

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00005935	0.000059	0.4611
Error	17	0.00218780	0.000129	Prob > F
C. Total	18	0.00224714		0.5062

Parameter Estimates

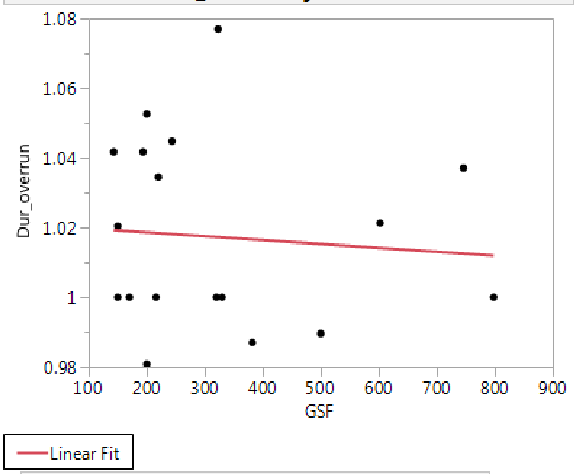
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.001221	0.004233	236.52	<.0001*
CIP	2.3513e-5	3.463e-5	0.68	0.5062

Regression analysis between GSF and time overrun

Fig. 12. Regression analysis of GSF's impacts on cost and time performance

Figure 13 is a regression analysis of CIP's impacts on cost and time performance. Results indicate that project contract values do not affect project cost and time performance.

Bivariate Fit of Dur_overrun By GSF



Linear Fit

Dur_overrun = 1.0208651 - 1.1177e-5*GSF

Summary of Fit

RSquare	0.007155
RSquare Adj	-0.05125
Root Mean Square Error	0.027096
Mean of Response	1.017275
Observations (or Sum Wgts)	19

Analysis of Variance

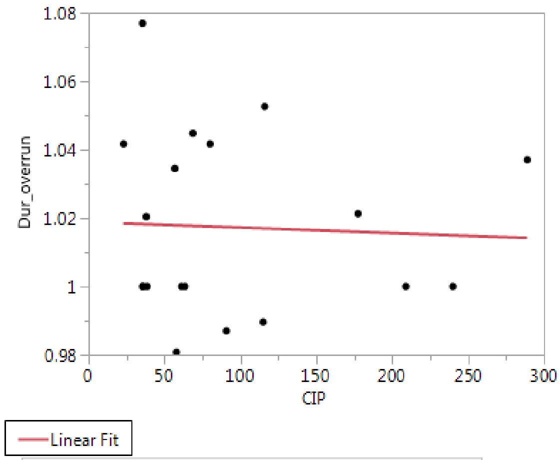
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00008995	0.000090	0.1225
Error	17	0.01248099	0.000734	Prob > F
C. Total	18	0.01257094		0.7306

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.0208651	0.011992	85.13	<.0001*
GSF	-1.118e-5	0.000032	-0.35	0.7306

Regression analysis between CIP and cost overrun

Bivariate Fit of Dur_overrun By CIP



Linear Fit

Dur_overrun = 1.0188199 - 1.6017e-5*CIP

Summary of Fit

RSquare	0.002191
RSquare Adj	-0.0565
Root Mean Square Error	0.027163
Mean of Response	1.017275
Observations (or Sum Wgts)	19

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00002754	0.000028	0.0373
Error	17	0.01254340	0.000738	Prob > F
C. Total	18	0.01257094		0.8491

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.0188199	0.010136	100.52	<.0001*
CIP	-0.000016	0.000083	-0.19	0.8491

Regression analysis between CIP and time overrun

Fig. 13. Regression analysis of CIP's impacts on cost and time performance

Discussion

Autonomous Agency

How stakeholders' autonomous actions on behalf of company strategy, but that run contrary to a project's best interest or produce unintended consequences, affect the operation of other stakeholders and other projects is a phenomenon not well understood or studied. Most studies concentrate on, are bracketed by, an individual project's concerns. The industry currently does not have a meta-project understanding that links the business of one stakeholder's project to that of all other ongoing projects of each stakeholder.

We pose the question: What could curb autonomous agency as the current working paradigm that adversely affects significant productivity increase efforts? Perhaps a rating system like that used for safety risk management in the construction industry could be implemented around a series of productivity indices such as PPC. For example, what would it be like, in scenario playing, if an owner has not only a company's EMR and IRR to assess safety risk, but also PPC to assess productivity risk as an item in its decision support system? Insurance and bonding companies could assign a cost to a low PPC just like they do to EMF and IRR in safety. Owners, especially in the public sector, could implement this rating system that in turn will, eventually, curb autonomous agency activity by assigning a cost and a risk. This could be a paradigm shift of the first order for the industry and one of significant cost implications, in the trillions both worldwide and in the USA.

Loose Coupling

In greater detail, this paper addresses the issue of project performance for lean and non-lean projects under various contracts. We assume that lean projects using the Last Planner system attempt to minimize autonomous agency actions by stakeholders that, because of the loose coupling of the industry, run contrary to a project's best interest. That is, projects done under the lean construction paradigm may limit autonomous agents' actions that negatively impact a project flow.

We pose another question: What could curb loose coupling, which adversely affects significant productivity increase efforts? In manufacturing, tight coupling that links the supply chain to the production effort results in a high level of control, and in construction, the current loose coupling system allows for the mobilization of resources to put out fires. The current real and significant contributions of LPS is that it establishes a third coupling system: honor coupling. When the group of all major foremen gather to hash out a project's schedule and promise their commitment to each other, there is an honor agreement that is powerful in curbing autonomous agency, despite the need to shift productivity from one foremen's project to put out another project's fire or to satisfy the company overselling its capacity.

Comparison of this Research to DB and LCF Findings

The aggregate industry research claims benefits by project delivery and by lean construction. Below is a chart of those claims versus the findings of this research.

Table 4. Projects in an economic cycle

Year	No. of projects	Economic cycle			
		Expansion	Boom	Recession	Depression
2000	2				x
2001	0	x			
2002	2		x		
2003	0			x	
2004	1				x
2005	2				x
2006	1	x			
2007	6		x		
2008	9			x	
2009	4				x
2010	7	x			
2011	4	x			
2012	3	x			
2013	4	x			
2014	9	x			
2015	7	x			
2016	11		x		
2017	1		x		

This research finds the claims between MBM and MBR regarding cost to be in line with that of other researchers, namely there is no appreciable difference, see Table 5.

Table 5. Comparative table of claims vs. This research

Claim	Source	This research
DB is the most effective in controlling cost growth (+2.8%) as compared with CMR (+5.8%) or DBB (+5.1%)	Sullivan et al. 2017	It shows that different project delivery methods do not affect cost performance.
No single delivery method consistently performs better on unit cost		Unit cost is not affected by project delivery methods.
CMR and DB were found to be the most accurate in controlling the schedule variation of a project, with an average schedule growth of +10.2 and +10.7%, respectively, as compared with a much higher +18.4% for DBB		Cost overrun is not affected by different contract pricing methods.
High Lean intensity projects were three times more likely to complete ahead of schedule	Dodge Data & Analytics 81 owners, 162 projects	Lean reduces project time overrun by 57.9%.
High Lean intensity projects were two times more likely to complete under budget		Lean projects do not outperform non lean project on cost performance.
24% of best (Lean) projects finished ahead of schedule compared to only 6% of typical projects		68.4% of lean projects finished ahead of schedule compared to 45% of non-lean projects.
46% of best (Lean) projects finished under budget compared to only 10% of typical projects		47.4% of lean projects finished under budget compared to 50.98% of non-lean projects.
61% of typical projects finished behind schedule		55% of non-lean projects finished behind schedule.
49% of typical projects completed over budget		49.02% of non-lean projects completed over budget.

Additional Contract Types

Future studies could include additional contract types such as lump sum, negotiated, cost plus, and sole service Provider. Other PDSs that could be considered in the future are: Design Bid Build (DBB); Construction Manager Agency (CMAG); Integrated Project Delivery (IPD); Bridging; and Finance, Design, Build, Operate, Maintain and Transfer (FDBOMT).

Solution from Two Directions

The solution to a systemic problem in the construction industry that is capable of radical transformation of the industry, like that of safety, needs to come from both above and below. From above, this solution is found by addressing the strategic plan of autonomous agency, and from below, through a pressure to honor plans and commitments from the tactical level, the foremen who are directly responsible to carry out the work. A conversation with the owner of a company now doing over $1B USD in annual construction in place summarizes the problem in the industry. When asked about the major construction problem that keeps him awake, he said it is loss of control in a project. Actually, a general contractor’s control of project production is reduced to contract agreements, but in reality, they have no control over the means and methods of the specialty contractor, concerning its labor and productivity actions, hence a general really has no clear lines of control over production. Therefore, regardless of the many inventions, techniques, and initiatives, there is no change in industry productivity vs. that of other industries.

Conclusion

This circles back to our original question: Do different management practices impact cost and schedule indicators? For the set of 70 mostly large commercial projects, this research indicates that neither project delivery system (DB or CMAR) nor Contract type (CSP or GMP) have substantially different cost and scheduled time performance differences, in contrast with published claims from other research. However, the results surprisingly indicate that there is a substantial improvement on the task transition in projects using MBM versus those using MBR, pointing to an undisclosed advantage. Our study attributes this advantage to a different coupling in MBM (honor coupling at the pull planning session of the Last Planner) and a more restrained use of autonomous agency in MBM projects versus MBR. Further work is merited to see if this same finding can be observed in smaller projects and from a combination of additional project delivery systems and contract types.

In summary, on the organizational level, each company focuses on improving project productivity in a loosely coupled system and as an autonomous agent. The worst-case scenario is to have capacity and no work. The best-case scenario is to have more work than capacity (overselling capacity as in the airlines industry). In reality, a company fluctuates from one to the other. Furthermore, in good times, the second scenario of having more work than capacity adversely affects productivity. In the next ten years, if construction continues to grow, it is our hypothesis that, as currently measured, efficiency and productivity will further decrease.

At a macro level, the alignment of a region's current and future projects with the capacity of the area's industry for a smoother project flow is an improbable task under the current systemic nature of the industry. Periodic economic cycles have reinforced a trend toward reduced margins, forcing autonomous agents to oversell capacity in order to extract higher profits from the workforce. Overselling capacity accentuates the overall downward trend of construction productivity in both up and down economic cycles, an unanticipated phenomenon. One envisioned solution requires smoothing out capacity allocation at both a single company and all the companies in a region, which is a highly unlikely event. However, this solution could create company level reporting of a productivity ratio, as with EMR/IRR in safety that is used by both public and private owners in selecting a service provider. This solution would add a level of predictability not currently available for such decisions, which would feed macro-level productivity measures.

Future Work

- *Research data collection, a continuing effort:* Using the same template, we expect to add a minimum of ten projects per year to the original set of cases. In five years, we should have between 50 - 75 additional projects that will be analyzed using the same techniques.
- *PPC and productivity study:* The MBM projects have a PPC segregated by building system. The correlation of PPC to project delivery system type, contract type, or economic cycle could also yield insights and interesting contrasts.
- *Cost and time studies:* Further research could be undertaken on cost and time performance within MBM and MBR by project delivery type and by contract type.
- *Economic cycle:* We have the data on the current set of projects to analyze MBM/MBR, PDS, and contract type regarding the year of completion and the economic cycle. This should shed light on the question: Can we discern how the economic cycle affects the industry?
- *Regional network:* A map of the regional network of service providers, along with their capacity to perform work, would constitute a high-level research project.

- *Does size matter?:* In conversation with general contractors and specialty contractors, we explored whether the size of a project matters in terms of autonomous agency decisions to shift productivity when a fire occurs on larger projects rather than on smaller ones. Would the results of a set of mostly smaller projects be different in cost and time between MBM and MBR?

References

Al Nasseri, H. A., Widen, K., and Aulin, R. (2016). A taxonomy of planning and scheduling methods to support their more efficient use in construction project management. *Journal of Engineering, Design and Technology*, *14*(3).

Alarcon, L. F. (1997). Tools for the identification and reduction of waste in construction projects. *Lean construction*, 365-377.

Bølviken, T., and Koskela, L. (2016). Why Hasn't Waste Reduction Conquered Construction? Eprintshud.ac.uk 3-12.

Fernández-Solís, J. L., Rybkowski, Z. K., Xiao, C., Lü, X., and Chae, L. S. (2015). General contractor's project of projects–a meta-project: understanding the new paradigm and its implications through the lens of entropy. *Architectural Engineering and Design Management*, *11*(3), 213-242.

Fernández-Solís, J. L., Lu, X., Ryoo, Y., B. (2013). Building construction: A deterministic non-periodic flow–A case study of chaos theories in tracking production flow. *Architectural Engineering and Design Management*, *9*(1), 21-48.

Fernández-Solis, J.L., Rybkowski, Z. K., (2012) "A Theory of Waste and Value", International Journal of Construction Project Management, 4(2), 1-6.

Fernández-Solís, J. L., (2008). The systemic nature of the construction industry. *Architectural Engineering and Design Management*, *4*(1), 31-46.

Fisher, R., *(1918). "Studies in Crop Variation. I. An examination of the yield of dressed grain from Broadbalk" (PDF). Journal of Agricultural Science. 11: 107–135.*

Forbes, L. H., and Ahmed, S. M. (2011). *Modern construction*. CRC Press.

Formoso, C. T., and Moura, C. B. (2009, July) Evaluation of the impact of the last planner system on the performance of construction projects, In *Proceedings of 17th Annual Conference of the International Group of Lean Construction* (pp. 153-164).

Gambatese, J. A., Pestana, C., and Lee, H. W. (2016). Alignment between lean principles and practices and worker safety behavior. *Journal of construction engineering and management*, 04016083.

Hamzeh, F., Zankoul, E., and El Sakka, F. (2016). Removing Constraints to Make Tasks Ready in Weekly Work Planning. *Procedia Engineering*, *164*, 68-74.

Hussein, A. I., and Zaid, K. (2016). Using Building Information Modeling (BIM) and the Last Planner System (LPS) to Reduce Construction Process Delay.

Johnson, H.T. (2006). *"Management by Means Brings Management to Life".* Encuentro de Excelencia Centro Humano de Liderazgo Juárez, México.

Johnson H. T. and Broms A. (2000). *Profit beyond measure: extraordinary results through attention to work and people*, New York: Free Press, c2000

Khanh, H. D., and Kim, S. Y. (2016), A survey on production planning system in construction projects based on Last Planner System. *KSCE Journal of Civil Engineering*, *20*(1), 1-11.

Kim, Y. and Ballard, G. (2010). "Management Thinking in the Earned Value Method System and the Last Planner System." *Journal of Management in Engineering*, 26(4), 223-228.

Kim, S. (2017). Manage-by-Means Approach in Construction Industry Through Process Mapping. *Advanced Science Letters*, *23*(3), 1512-1516.

Koskela, L. and Howell, G., 2002a, *"The underlying theory of project management is obsolete"*, in D.P. Slevin, D.I. Cleland and J.K. Pinto (eds.): Proceedings of PMI Research Conference 2002, Project Management Institute, 293–302.

Koskela, L., and Howell, G., 2002b, *"The Theory of Project Management – Problem and Opportunity,"* Working Paper, VTT Technical Research Center of Finland and Lean Construction Institute.

Lean Construction Institute (LCI), https://www.leanconstruction.org/ accessed April 25, 2017.

National Institute of Building Sciences (NIBS), https://www.nibs.org/ accessed April 25, 2017.
McConaughy, T., and Shirkey, D. (2013), Specialty contractors collaboration and breakdowns in production: the effects of varied LPS implementation. In *Proceedings for the 21st Annual Conference of the International Group for Lean Construction*.
Naoum, S. G. (2016). Factors influencing labor productivity on construction sites: A state-of-the-art literature review and a survey. *International Journal of Productivity and Performance Management*, *65*(3), 401-421.
Nepal, M., Park, M., and Son, B. (2006). "Effects of schedule pressure on construction performance." *Journal of Construction Engineering and Management*, 132(2), 182–188.
Olivieri, H., Seppänen, O., and Granja, A. D. (2016). Integrating LBMS, LPS and CPM. In *Annual Conference of the International Group for Lean Construction*. International Group for Lean Construction.
Porwal, V., Fernández-Solís, J. L., Lavy, S., and Rybkowski, Z. K. (2010, July). Last planner system implementation challenges. In *Proceedings of the 18 Annual Conference International Group for Lean Construction, IGLC* (Vol. 18, pp. 548-54).
Priven, V., and Sacks, R. (2016). Impacts of the Social Subcontract and Last Planner System Interventions on the Trade-Crew Workflows of Multistory Residential Construction Projects. *Journal of Construction Engineering and Management*, 04016013.
Puddicombe, M. S., and Johnson, B., 2012, *"Research and Theory Building in Construction Management."* International Journal of Construction Education and Research, Routledge 7(2) 126-142.
Rojas, E. M., and Aramvareekul, P. (2003). Is construction labor productivity really declining?. *Journal of construction engineering and management*, *129*(1), 41-46.
Sacks, R. (2016). What constitutes good production flow in construction?. *Construction Management and Economics*, *34*(9), 641-656.
Sacks, R., Seppänen, O., Priven, V., and Savosnick, J. (2017). Construction flow index: a metric of production flow quality in construction. *Construction Management and Economics*, 1-19.
Sterman, J. D. (1992). "System Dynamics Modeling for Project Management." MIT Sloan School of Management.
Sullivan, J., Asmar, M. E., Chalhoub, J., and Obeid, H. (2017). Two Decades of Performance Comparisons for Design-Build, Construction Manager at Risk, and Design-Bid-Build: Quantitative Analysis of the State of Knowledge on Project Cost, Schedule, and Quality. *Journal of Construction Engineering and Management*, 04017009.
Teicholz, P. (2013). "Labor-productivity declines in the construction industry: Causes and remedies (another look) -- AECbytes Archived article." <http://www.aecbytes.com/viewpoint/2013/issue_67.html> (Dec. 12, 2015).
Teicholz, P., Goodrum, P. M., and Haas, C. T. (2001). US construction labor productivity trends, 1970–1998. *Journal of Construction Engineering and Management*, *127*(5), 427-429.
Viana, D. D., Mota, B., Formoso, C. T., Echeveste, M., Peixoto, M., and Rodrigues, C. L. (2010, July). A Survey on the Last Planner System: impacts and difficulties for implementation in Brazilian companies. In *Proceedings of the 18th Annual Conference of the International Group for Lean Construction, IGLC* (Vol. 18, pp. 497-507).
Vrijhoef, R., and Koskela, L., 2005, "Revisiting the Three Peculiarities of Production in Construction".
Vrijhoef, R., and Koskela, L. (2000). The four roles of supply chain management in construction. *European journal of purchasing and supply management*, *6*(3), 169-178.
Xiao, C., and Fernández-Solís, J. L. Are Building Construction Delivery Systems Complicated or Complex? In *Construction Research Congress 2016* (pp. 1844-1854).
Xiong, G and Nyberg T.R., (2000). "Push/pull production plan and schedule used in modern refinery CIMS, Robotics and Computer-Integrated Manufacturing." 16 (6), 397-410.